EnviroInfo 2006 (Graz)
Managing Environmental Knowledge

Indicators for Water Information Systems

Helmut Markus Knoflacher[1], Ute Gigler

Abstract

The basic role of indicator systems is the structured provision of information for decisions from observation and readings. The development of Indicator systems for the water management is an interdisciplinary task which contains technical, organizational and mental aspects. Despite the impulses of the European water framework directive for indicator harmonization, a need for an efficient design of the waters management and for methods for the integration of data of different qualities can be expected. By the combination of system analytical methods with operative methods of the database management as well as suitable organizational measures, in the long run the requirements of the European water framework directive can be fulfilled in the constraints of the existing financial and personnel framework conditions.

1. Introduction

The great variety of indicators in water information system of aggravates the comparability of information and the assessment of the effects of measures. During the preparing discussions and the putting into action of the European water framework directive numerous work was done to improve the comparability of information about water conditions and the effects of measures at a European level by the harmonization of indicators for water information systems. These frame regulations leave, however, one more number of important questions open for practical applications. So it has to be cleared, which indicators have to be used for the management of water resources at a local and regional level or how data already consisting from earlier recording periods can be compared with the data of the new indicator systems.

Of special significance for use of indicators is their applicability for social decisions or the design of measures. The possibilities for the derivation of information and of deciding factors are prerequisite for the selection of indicators. The separating sharpness is not at all alone determined by measuring precisions in complex systems, it is rather as well as the spatial and temporal modeling precision of the observed processes. The information content of indicators depends strongly on the action context of the respective target groups. So data can have high information content from measuring rows for experts, for example, but only a low information content for decision maker in the economy or politics. Similar applies to multi-factorial indicator systems, been able to these have high information contents in detailed representations for experts, but information can be offered only in aggregated form for decision makers.

In this contribution the view of systemic connections turns into the framework conditions and potential solution ways treated of water catchment areas and exemplarily for some action fields derived for these questions. The system adequate reduction in the complexity of physical systems is of central importance for the development of indicators in the action frameworks of the acting protagonists (Chernoff/Moses, 1959; Malik, 1977; Bacharach/Hurley, 1994; Lasdon, 2002). In the ideal case essential changes of the environmental systems shall be registered by the indicators and sufficient information should be provided for the action defining decisions of the protagonists.

[1] ARC systems research, Donau-City-Straße 1, A.1220 Wien
email: markus.knoflacher@arcs.ac.at

2. Requirements on indicators from the system terms of the water use

2.1 Requirements on indicators from the general characteristics of water catchment area

Water catchment areas contribute to the global water cycle by the drain of the precipitations, by evaporation and storage of water. These functional performances are determined by the framework conditions of the climate, the geomorphology, geology and the biotic processes in the catchment areas in interaction with the precipitations (White/Mootershed/Harrison, 1992; Moldan/Černý, 1994). The complexity of the interactions does not permit any complete recording of all processes in the catchment areas (H.M. Knoflacher, 2001). By the framework conditions, the parallel running but not linearly connected to the water movements, processes of the substance transports in the catchment areas are influenced fundamentally. Because of the fractal features of the spatial and temporal processes, no characteristic scales from the systemic features of the water catchment areas can be defined and thus also no scale related requirements can be derived for these for monitoring systems (Rodriguez-Iturbe/ Rinaldo, 2001). Such requirements can be intended only for concrete questions or task positions. The definition of the questions is independently of the temporal and spatial dimensions but always based on social ideas and specifications. This integration of the information extraction in a certain context of ideas makes only decisions possible under complex environmental conditions.

Water catchment areas are open systems and therefore not characterized by clear cause effect relationships. The recording of interactions between functionally connected parameters can therefore always be carried out only with restricted precisions. Functional connections between different parameters are usually provable for these reasons only by temporally coordinated observations of the recorded parameters. Unlike examinations under laboratory terms with fixed framework conditions (Knoch, 1991), at examinations unknown or non-recorded influence sizes can change the connections between the watched parameters in catchment areas.

2.2 Recording of anthropogenic changes in catchment areas

The recording of anthropogenic changes in catchment areas counts the most essential tasks of the monitoring and the information extraction at supervisions of the water quality and the check of measures. The range of anthropogenic and relevant for the water balance changes in catchment areas reaches from interventions in the geological conditions and transformations of the vegetation until emissions into waters and water transfer to other catchments (Canter/Knox, 1985; Jungwirth/Muhar/Schnmutz, 2000). The complexity of the anthropogenic changes in the catchment areas and its interactions with the natural processes prevents complete recordings by monitoring systems. Single anthropogenically conditional changes are ascertainable all the more easily the more strongly it is different from the features of other processes in the catchment areas in its temporal or spatial characteristics or in physical and chemical features. For example the changes caused by single sources, standing out in their dimension or quality, are more easily ascertainably than changes caused by diffusely distributed sources.

Besides the methodical challenges additional requirements by the asymmetrical effect relations arise at the interactions between the social systems and the physical systems of the environment. Asymmetrical effect relations are characterized by the distribution of advantages and disadvantages on different groups of actors. The dissimilar distribution can at the same time take place or be realized in different time periods. Under such terms profound disturbances only can be avoided by a third group of actors in the catchment areas, with sufficient information of the consequences appearing and sufficient power to take measures into action. These tasks require sufficiently protected proofs of the connections between the actions charging potentially and the negative changes watched, and the preparation of sufficient information about the realization of measures. Information is suitable when through this the target groups concerned are arranged for the reduction of the charging activities.

This requires the consideration of the action context of the target groups at the development and appropriation of information (H.M. Knoflacher, 2002). Transformations are necessary between different dimensions, for example between scientific and economic dimensions (Costanza, 1991). It is important that the transformed dimension is actually taken into account at decisions in the target groups. The putting into action of measures can be supported by social rules and laws appropriately only at sufficient control possibilities.

2.3 Objectives of the water management and their features

Defining objectives of the water management are the preservation of the human basic living conditions and the human health, the preservation of the ecological function ability and the preservation of the production bases. Multi-dimensional claims are distinctive for the objectives quantities as well as the chemical and physical qualities of the water. As a rule, the connections between change intensities and the consequences at the objective sizes are not linear; U-shaped active functions have often to be watched with an optimal area at middle change intensities (Marquardt/ Schäfer, 1994; Schüürmann/Markert, 1998). The most complex claims to indicators are connected to the preservation of the ecological function ability of the waters, since it covers all organization levels of long-term relationships and all interactions between the organisms and abiotic parameters.

These objective sizes are substituted by partial objectives, for example waters quality, drinking water quality or biological water quality in the practice. This process way approaches the social sub-structure of the water management and makes the summary of the relevant indicators easier for the respective areas of responsibility. However, the sub-structure can lead also there to problems where a information is used for control of different partial objectives. Such problems can be solved only about social appraisal processes with the objective of a hierarchical classification of the controversial indicators. If the inconsistencies between the appraisals of different areas of responsibility concern also multiple indicator systems, then the known functional interactions also must be taken into account between the parameters at the solutions. Otherwise the practical attainment of the objectives fails because of the contrary reactions of the waters systems.

3. Development of Indicator Systems

3.1 Theoretical concept of the indicator development

3.1.1 General requirements for the extraction of information from observations

Indicators are needed for the interpretation of system states and for decisions. Indicators methodically are needed for the extraction of relevant information from observations. At the observation of complex systems different aspects contribute to the information extraction:

- The structural aspect concerns the choice of observation parameters as well as the specification of the spatial and temporal distributions of the observations.
- The operative aspect concerns the choice of suitable measuring methods for the single observation parameters and the choice of methods for the extraction of data from the observations.
- The cognitive aspect concerns the choice of suitable methods for the extraction of information for different protagonists from the data.

The specific features of the watched factors and their interactions are taken into account in the structural aspect, this is based on existing knowledge of the observed system. Differences of the dynamic features can be taken into account by different observation frequencies, different spatial distribution by the suitable distribution of observation points. Interdependencies between the factors can be included by a suitable synchronization of the observation frequencies and by the coordination of the spatial distribution of sampling sites.

The choice and specification of suitable investigation and data extraction methods is carried out in the operative aspect. The results of the structural aspect ideally are taken into account by adjustment of the measuring methods to the requirements of the observation frequencies and the spatial distribution of the observation points. It has to be taken into account here that faults in the structural aspect cannot be compensated for any more in the operative aspect. The choice of the methods for the extraction of data from the observation sizes is at the interface between the requirements for the observation of the system in question and the requirements of the information extraction. As a rule, multistage proceedings for the appropriation of data are applied to different levels of aggregation.

The cognitive aspect deals with the perception of information by different protagonists at the representation of results of the data analysis. Important factors for the choice of the representation methods are the technical knowledge and the action context of the protagonists. The technical knowledge results from the level of training, the action context from the area of responsibility of the protagonists. Protagonists with similar levels of training but different areas of responsibility can have therefore different requirements on information. So for example an expert can have a need for detailed information in the expert service, a need for high aggregated data an expert with management function.

Under the complex terms of water catchment areas information about system states and their changes can be measured only with limited precision. Because of the large number of system elements in these systems, the number of the possible interactions is very large and at restricted resources not ascertainable completely for the observation. The set of possible decisions can finally be under such terms only with a finite amount of observation of functionally coherent factors. Interpretable results of observations have therefore only then to be expected if the choice of the observation sizes as well as the temporal and spatial distribution of the observations a-priori is fixed. These specifications must be carried out on the basis of checkable hypotheses. With increasing shares of factors non-being connected functionally in the set of the observation parameters an increase has to be expected for stochastic relations between the observation data. Deviations of this assumption have to be expected if an additional factor influences the observed factors.

3.1.2 Specific requirements for the water management in catchment areas

Essential tasks of the water management in catchment areas are the compliance with socially desired set conditions and the coordination of different interests in the context of these requirements. Information about the current system states, the regular anthropogenic influences, the physical features of the catchment area and the measures used, is needed for the fulfillment of these formulations. The following indicator groups are deduced from it:

- Control indicators: They contain all indicators for the recording of the system states; for example groundwater all indicators of the groundwater swelling value ordinance.
- Impact indicators: They contain all indicators about anthropogenic influences on waters, for example issues from individual sources or from diffuse sources.
- Indicators of functional conditions: They contain all indicators about the processes of the water movements and terms with regard to substance transports in the catchment areas. Examples of it are hydrogeologic factors, climatic factors or drainage investments.

- Indicators of measures: They contain indicators about the way and the extent of taken measures and control of their putting into action. Examples of it are protection area ordinances, supports of certain economy ways, prevention of water pollution stripes.

Since the individual indicators as a rule are surveyed and processed by different institutions, the realization of a water management system is influenced by organizational framework conditions also fundamentally. A prerequisite for the establishment of a water management system is the organizational protection of the information logistics. This includes the exchange of data and information between the involved institutions and the appropriation of the technological facilities and methods necessary for it. The appropriation of methods for the integration of data and information with different features also has to be assigned to this area of responsibility. The second organizational framework condition concerns the coordination of the involved institutions at the execution of the observations as well as the development and execution of measures.

So an efficient water management system needs protected organizational framework conditions and sufficient information to be able to be aware of the following tasks:

At the <u>supervision on critical changes</u> the information is needed for critical changes from the control indicators for the regular documentation of the conditions and for accurate and objective exact warnings. The documentations of the conditions is regularly based on statistical methods. Application-oriented users shall get summary of the conditions and developments of the watched environmental parameters; scientific users are interested on results of special analyses. The expected information contents reach subtly from reduced information for political protagonists to very detailed information for scientific protagonists.

Accurate and objective exact warnings about critical changes can dynamically derived from the evolutional trends of measurements or from differences to threshold values. The dynamic method is normally used for regular control of production processes or the regular supervision of large water supply facilities. The direct application of the information is characteristic for such systems in heading interventions. The static method is used mainly for systems with indirect control possibilities, for example for control in environmental systems. The information need is to support the two methods in the clear expulsion of the indicators with critical changes. Information about other indicators is of importance in this action step only when it offers additional support for decisions for example by differential analyses.

The <u>preparations for measures</u> due to monitoring results are necessary only when critical changes were observed. Because of the complex interdependences in environmental systems, additional information about influence potentials and influence conditions are needed for the identification of the relevant, triggering factors. The causes of the critical changes can be identified all the more easily the better the spatial and temporal samples of the influence processes were included in the observations. Next to the application of hybrid evaluation proceedings for the reconstruction of the development of changes, additional surveys can become necessary for select indicators for the preparations for measures.

The <u>check of the measure effectiveness</u> represents in principle the supervision on critical changes. Deviations of the original process way can be caused, however, by new knowledge at the preparation and putting into action. Examples of such deviations would be the application of new indicators or modifications of the temporal or spatial resolution in the monitoring system. However, it is recommends to save the possibilities for transformation between the data of the original monitoring period and the following monitoring periods. Potential solutions are overlapping periods for subsequent monitoring systems.

3.1.3 Requirements of relevant actor groups for the water management

By the requirements of the water framework directive a considerably higher coordination need between different protagonists than till now is required. Also new requirements on the appropriation of information are connected to that for different actor groups. There were individual measures in the previous practice in the foreground, where these the differences could be evened out in the information need by the explanations of well-informed persons. For the planning and putting into action of measures under consideration of the consequences in the respective catchment area the required information must, however, understandably and in keeping with requirement be processed for the different actor groups, to support the decision processes. The following actor groups can in simplified terms be summarized with different information need:

Group A) High resolution of the indicators and precision required: Facilities of water quality control, experts, and scientific institutions.

Group B) Partial aggregations of indicators and expulsion of statistical identification values required: Planning institutions, statistical institutions, qualified public persons.

Group C) High aggregate ion of indicators and expulsion of condition classes required: politicians, general public.

There are specific requirements for economic facilities for the use of waters, for example water public utilities or power station enterprises. The specific information need and the precision requirements on data can be in domain of their far over those of the group of A). There can be also special claims to the temporal resolution of the data and the spatial distributions of the monitoring sites.

3.2 The application of indicator systems

3.2.1 Framework conditions

The framework conditions for indicator systems practical putting into action are determined by the existing legal and administrative regulations, the available resources and the day to day business of application. Requirements from primary regulations, such as the water framework directive, can be fulfilled only in long-term putting into action processes. In the reality a great variety of organizational framework conditions actually realized and of different information is therefore found. Besides the rearrangement of existing systems to the requirements of the water framework directive, in future, it will be necessary to use data and information from documentations already consisting, too. Temporal changes can be included sufficiently and taken into account at the development of measures only in such a way. Because of the restricted resources for the realization of water management systems, there is the necessity also for the comprehensive efficient design of the monitoring and the organizational framework conditions. Otherwise there is the danger that by exaggerated activities in individual areas the complete effectiveness of water management systems is lost.

3.2.2 Example of the use of heterogeneous data sources

In contract of the office of the Upper Austrian Land government the nutrient levy of surface waters was carried out from diffuse sources for the Innbacheinzugsgebiet (Knoflacher/Gebetsroither/Köstl, 2002). Only already available data were used for the examination from different sources. Date sources were survey data of the official water quality monitoring system, short term data with high temporal resolution for one site, precipitation and runoff data of hydrographic monitoring sites, land use data from multi-temporal satellite remote sensing surveys, digital elevation model, soil data and statistical data.

Because of the different data qualities, a risk approach which permits the explicit consideration of probabilities was methodically chosen. The structure concept of the indicators represented above methodically was used. Measure indicators were expected from it since in the context of the project no development of the measure was scheduled. The spatial and temporal data operatively were brought together and managed in a geographical information system. The exchange of data and results for supplementary model calculations was carried out via interfaces between the used programs.

It could be demonstrated by the achieved results that critical zones and activities can be identified on the basis of existing, heterogeneous data. The results make the specific preparations for measures and the planning of detailed additional elevations possible for the putting into action of the measures.

4. Summary

The development of indicator systems for water management systems requires the consideration structural, operative and cognitive aspects as well as the organizational framework conditions. The targets of the water management are of decisive importance for the choice of the methods and process ways. Since the theoretical requirements cannot be fulfilled for indicator system development for different reasons in the practice, an additional need for transformation methods consists for the integration of indicators of heterogeneous sources. It could be demonstrated for applied examples that important contributions to the water management can be made by application of appropriate transformation methods.

Acknowledgements

This publication is based on the work for the project WATERMARK of Seibersdorf Research GmbH.

Bibliography

Bacharach, M., Hurley, S. (1994): Foundations of decision theory, Blackwell.

Canter, L.W., Knox, R.C. (1985): Groundwater Pollution Control, Lewis Publishers.

Chernoff, H., Moses, L.E. (1959): Elementary decision theory, Dover Publications.

Costanza, R. (1991): Ecological Economics, Columbia University Press.

Jungwirth, M., Muhar, S., Schmutz, S. (2000): Assessing the Ecological Integrity of Running Waters, Kluwer Academic Publishers.

Knoch, W. (1991): Wasserversorgung, Abwasserreinigung und Abfallentsorgung, VCH.

Knoflacher, H.M. (2001): Dealing with Scaling Problems in Surface Water Quality Management in Upper Austria, In: Ghassemi F., Post D., Sivapalan M., Vertessy R. (eds.): MODSIM 2001, Proceedings, Canberra, ISBN 0 86740 525 2, pp. 239-244

Knoflacher, H.M. (2002): A Conceptual Model for Integrated Assessment, In: Integrated Assessment and Decision Support Proceedings of the 1st Biennial Meeting of the International Environmental Modelling and Software Socienty; IEMS Congress; Vol. 3; ISBN 88-900787-0-7; pp. 121-126

Knoflacher, H.M., Gebetsroither, E., Köstl, M. (2002): Einträge von Stickstoff und Phosphor aus diffusen Quellen im Innbacheinzugsgebiet, Gewässerschutz Bericht 27/2002, Amt der Oberösterreichischen Landesregierung.

Lason, L.S. (2002): Optimization theory for large systems, Dover Publications.

Malik, F. (1977): Strategie des Managements komplexer Systeme. Haupt.

Marquardt, H., Schäfer, S.G. (1994): Lehrbuch der Toxikologie, BI Wissenschaftsverlag.

Moldan, B., Černý, J. (1994): Biogeochemistry of small catchments, Wiley.

Rodríguez- Iturbe, I., Rinaldo, A. (2001): Fractal River Basins, Cambridge University Press.

Schüürmann, G., Markert, B. (1998): Ecotoxicology, Wiley.

White, I.D., Mottershead D.N., Harrison, S.J. (1992): Environmental Systems, Chapman&Hall.